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Amphibious Assault Ship Hangar Bay Smoke-Removal Tests Conducted Onboard the USS *Bonhomme Richard* (LHD-6)

by

Michelle J. Peatross
Arthur J. Parker
Robert L. Darwin
Hughes Associates, Inc.
Baltimore, Maryland
and
Howard L. Bowman, Glenn E. Risley, and Ross A. Davidson
Engineering Sciences Division
Research Department
Naval Air Warfare Center Weapons Division

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NAVAL AIR WARFARE CENTER WEAPONS DIVISION
CHINA LAKE, CA 93555-6100

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Naval Air Warfare Center Weapons Division

FOREWORD

This report summarizes work performed onboard the U.S.S. *Bonhomme Richard* (LHD-6) for smoke removal and ventilation tactics of amphibious assault ship hangar bays. The objective of this test program was to describe preliminary scoping tests conducted for the purpose of providing guidance on changes to the ventilation procedures described in the NATOPS Firefighting Manual. The test results were used to provide recommendations for changes to the doctrine.

During these scoping tests, smoke generators were used to evaluate techniques for smoke removal from the hangar bay onboard the USS *Bonhomme Richard* (LHD-6). Visibility within the hangar bay was used as the measure of performance. The effect of door status and wind direction was evaluated. Doors that were used included the elevator doors, the door at the top of the well deck ramp, and the door at the top of the flight deck ramp. The effects of crosswinds and headwinds were evaluated for the different door configurations. In addition, the effect of using mechanical supply from the well deck to pressurize the hangar bay was investigated.

This report was reviewed for technical accuracy by T. L. Boggs.

Approved by
T. ATIENZAMOORE, *Head*
Engineering Sciences Division
4 December 2003

Under authority of
D. VENLET
RDML, U.S. Navy
Commander

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Michelle J. Peatross, Arthur J. Parker, Robert L. Darwin, Howard L. Bowman, Glenn E. Risley, and Ross A. Davidson

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13. ABSTRACT *(Maximum 200 words)*

(U) The objective of this test program was to conduct preliminary scoping tests onboard the USS *Bonhomme Richard* (LHD-6) for the purpose of providing guidance on changes to the ventilation procedures described in the current doctrine.

(U) During these tests, smoke generators were used to evaluate the removal-performance from the hangar bay with various door configurations and ventilation conditions. The visibility in the hangar bay was used as the measure of performance. The effect of door status and wind direction/speed was evaluated. Doors that were used included the port and starboard elevator doors, the flight deck ramp door, and the well deck ramp door. The effect of crosswinds and headwinds was evaluated. In addition, the effect of using the well deck supply fans was assessed.

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1.0 INTRODUCTION

Current US Navy firefighting doctrine requires that in the event of a fire in the hangar bay of an amphibious assault ship, all fire and elevator doors be closed immediately (Reference 1). Closing the doors will contain the fire, minimize the introduction of fresh air (which could increase the fire growth), and prevent further fire spread to unaffected areas of the ship. However, by closing the elevator doors, smoke and heat will accumulate within the hangar bay, severely reducing the visibility for firefighting personnel. Reduced visibility results in disorientation and deterioration of communications among the ship's crew in addition to reduced firefighting performance.

Additional ventilation guidance is provided in Reference 1, Section 8.7.6 of Chapter 8 (as a note) stating, "Leave one elevator door open approximately 3 feet to facilitate venting of smoke. Request ship execute a turn in order to position the open door to leeward." The doctrine is interpreted to mean that the door should be open while firefighting operations are being performed (i.e., active desmoking).

The guidance provided in Section 7.7.7 of Reference 1 for aircraft carriers is not consistent with that in Section 8.7.6. It states that all fire and elevator doors should be closed immediately. As a note, it then says to "... Cross ventilate to facilitate venting of smoke. Utilize ship's direction to maximize ventilation efforts." Considering that the elevator doors are normally open to some degree in good weather, closing doors only to open them later is contradictory. The inconsistencies in the guidance provided in Chapters 7 and 8 resulted in the need to conduct tests to determine the appropriate door settings for maximum ventilation.

The effects of reduced visibility on firefighter performance have been observed in a number of manned tests conducted in small, below-deck spaces onboard the Navy's full-scale research, development, test, and evaluation (RDT&E) facility (ex-USS *Shadwell*, located in Mobile, Alabama) (References 2, 3, 4, and 5) and during an actual fire involving hazardous materials onboard the USS *George Washington* (CVN-73) (Reference 6). Testing conducted onboard the *Shadwell* followed current doctrine where the mechanical ventilation system was secured upon report of the fire. In these tests, the Fleet participants were unable to perform firefighting operations (dressing out, advancing hose lines, extinguishing the fire, and maintaining boundaries) because of the intense heat and reduced visibility. During the aircraft-carrier hangar-bay fire, all doors were closed during firefighting operations (per doctrine), resulting in heavy smoke, heat accumulation, and reduced visibility. The reduced visibility and excessive heat hampered firefighting efforts by preventing the fire teams from finding the hose lines, reaching the seat of the fire for an extended period of time, and extinguishing the fire (Reference 6).

Previous testing demonstrated the effectiveness of establishing ventilation pathways to remove heat and smoke from the fire space during firefighting operations using natural and mechanical ventilation (References 2, 3, 4, and 5). In a hangar bay, the opening of the doors may permit venting of the fire space, restoration of visibility, and lowering the heat threat within the hangar bay. Additionally, natural crosswinds created by changing the course and speed of the

ship, and opening both windward and leeward side doors may further aid in the smoke and heat removal process.

To identify the most effective smoke removal techniques and recommend more clear doctrine procedures, ventilation testing was conducted onboard a *Nimitz*-class aircraft carrier, the USS *Eisenhower* (CVN-69) (Reference 7). These tests examined the effect of wind direction and door position (elevator, division, and sponson) on the smoke-removal rates for the three hangar bays. Evaluation of each hangar bay was necessary because they had different arrangements of elevator and personnel doors that opened to weather. The results showed that opening an elevator door 1 meter (m) (3 feet (ft)) had minimal effect on smoke removal from the hangar bay, regardless of the ambient wind conditions. Smoke removal was the quickest when doors were opened on the port and starboard sides of the hangar bay. For situations where elevator doors were on each side of the hangar bay, the results suggested that the most effective door configuration was to open the leeward door halfway and the windward door 1 m (3 ft) (assuming that the ship has turned to create a crosswind).

Because the doctrine is conflicting for aircraft carriers and amphibious assault ships, and the hangar bay configurations are different, testing on amphibious assault ships was necessary.

OBJECTIVE

The objective of this test program was to conduct scoping tests onboard the USS *Bonhomme Richard* (LHD-6) for the purpose of providing guidance on changes to the ventilation procedures described in the current doctrine. The test results were used to recommend changes to the doctrine.

APPROACH

Smoke generators were used onboard the USS *Bonhomme Richard* (LHD-6) to evaluate the smoke removal performance from the hangar bay with various door configurations. Visibility within the hangar bay was used as the measure of performance during these tests. The effect of door status and wind direction was evaluated. Doors that were used included the elevator doors, the flight deck ramp door, and the well deck ramp door. The effects of crosswinds and headwinds were evaluated for the different door configurations. In addition, the effect of using supply ventilation from the well deck to pressurize the hangar bay was investigated.

HANGAR BAY TEST SETUP

The test setup for all tests included smoke generators to fill the hangar bay with smoke (i.e., cold smoke), visibility targets for observers to view, and the door configurations being evaluated. Fleet participants from the USS *Bonhomme Richard* (LHD-6) assisted in the test setup, participation, and cleanup.

USS *BONHOMME RICHARD* (LHD-6) HANGAR BAY

The *Wasp*-class amphibious assault ships have one hangar bay located on the main deck, spanning from FR 83 to FR 120 and nearly the entire width of the ship. The hangar bay has two elevator doors (Figure 1). One of these doors is located in the forward portion of the hangar bay on the port side. The other door is located on the starboard side in the aft portion of the bay. The elevator doors require approximately 42 seconds to close fully. No provision exists for mechanical ventilation in the hangar bays. To provide ventilation in the hangar bay, one or both of the hangar bay doors are typically one-quarter open, weather permitting.

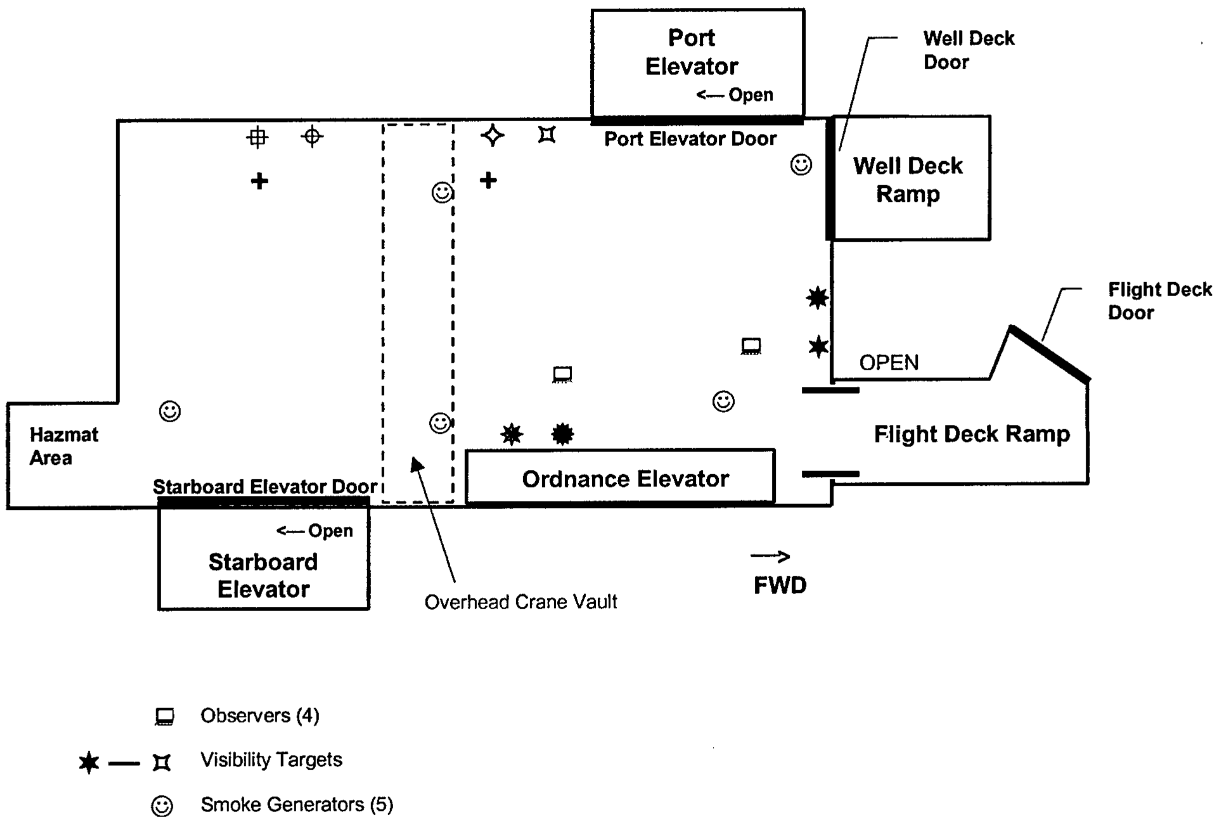

FIGURE 1. Setup for Hangar Bay Smoke Testing.

The hangar bay was relatively open during the testing (i.e., no parked aircraft) with only normal equipment and materials being stored The dimensions of the hangar bay are provided in Table 1. The gross volume is based on the height, width, and length of the area. The net volume accounts for the addition of the hazmat area, the overhead crane vault, and the flight deck ramp. Dimensions of these areas are also given in Table 1. It was assumed that 80% of the hazmat area is not filled with equipment. The volume of the flight deck ramp was included because it is open to the hangar bay. In addition, the volume of the weapons elevator area and miscellaneous stored equipment was subtracted from the gross volume to obtain the net volume.

As shown in Figure 1, a ramp that leads down to the well deck is located in the forward end of the hangar bay. A roll-up door at the top of the ramp serves as a smoke barrier.

TABLE 1. Hangar Bay.

Length, m (ft)	Width, m (ft)	Height, m (ft)	Gross volume, m^3 (ft^3)	Net volume[a], m^3 (ft^3)
Hangar Bay				
81 (266)	23 (76)	7 (22)	12,600 (444,750)	13,846 (488,600)
Hazmat Area				
21 (70)	12 (40)	7 (22)	---	---
Overhead Crane Vault				
10 (32)	23 (76)	2 (8)	---	---
Flight Deck Ramp				
41 (135)	3 (9)	4 (14)	---	---
Weapons Elevator				
33 (107)	3 (11)	7 (22)	---	---

[a] Includes the hazmat area, overhead crane vault, and flight deck ramp. Does not include weapons elevator area and stored equipment.

SMOKE GENERATORS

Smoke was introduced into the hangar bay using five smoke generators. Four of these generators were owned and maintained by *Bonhomme Richard* personnel. *Bonhomme Richard* smoke generators were manufactured by Symtron Systems Inc. (Model Smokemaster SM-3KB) and operated with Symtron Fog Fluid. The other generator was provided by Naval Air Warfare Center Weapons Division (NAWCWD) China Lake personnel. This generator was a Rosco 1600 fog machine operated with Rosco Fog Fluid.

The smoke generators were positioned throughout the hangar deck to provide equal filling. Approximately 30 minutes were required to fill the hangar bay with smoke using five smoke generators. The filling time was defined as the time from the start of the test to the time that all visibility observers would lose sight of their targets or that the test director determined that a sufficient quantity of smoke was present in the hangar bay. In cases where visibility of one target was not lost because of its location, a decision was made by the test director to commence ventilation rather than delay the test. In these cases, the entire hangar bay was filled with a sufficient amount of smoke to allow for a meaningful assessment of the ventilation performance.

VISIBILITY TARGETS

Eight visibility targets were used to determine the effectiveness of each particular ventilation configuration. These targets consisted of white cardboard signs (22 by 28 cm (8.5 by 11 in.)) with a red cross painted on them (19 by 19 cm (7.5 by 7.5 in.)). The signs were hung

approximately 1.5 m (5 ft) high on bulkheads. A single observer was used for two targets. One target was 6.1 m (20 ft) away and the other was 9.1 m (30 ft) from the observer. Targets were located on the bulkheads by the ordnance elevator, between the well deck and flight deck ramps, opposite from the starboard side elevator door, and aft of the port elevator door (see Figure 1).

All of the observers were assigned a number for each pair of targets. The observers called out these numbers when visibility was lost and when visibility was recovered. One of these four observers was a USS *Bonhomme Richard* crew member and the others were members of the test team.

TEST PROCEDURES

Before each test, all of the elevator doors, ramp doors, and personnel doors around the perimeter of the hangar were closed. Safety monitors (Fleet personnel) were positioned at each personnel door, on the outside of the hangar bay, to prevent non-test personnel from entering the space during a test. Fleet personnel were available to operate elevator doors, the flight deck ramp door, the well deck ramp door, and well deck supply fans as requested by the test director.

A prebrief was conducted before each test to detail the anticipated hangar bay conditions, to review the call-out procedure for visibility of the targets, and to explain the door configuration to be evaluated. Once all visibility targets, observers, and hangar bay doors were prepared, the test director announced the start of the test and power was turned on to the smoke generators. As the hangar bay filled with smoke, the observers were instructed to notify the test director after either target became obscured for more than 5 seconds. When all targets were obscured, or the test director determined that the conditions were sufficient to start ventilating, Fleet personnel coordinated with the bridge to achieve the desired ambient wind conditions (i.e., crosswind or headwind).

Upon achieving the desired outside wind conditions (or as close as possible), the particular door configuration was initiated to begin clearing smoke from the hangar bay. When the visibility increased to the point where the visibility targets could be seen, the observers notified the test director. If a period of 5 minutes passed and at least two targets were not visible, the door configuration was changed. In some cases, the door configuration was also changed to determine if further improvements in visibility could be made. The smoke generators continued to produce smoke as the doors were opened, simulating a fire that was still burning (i.e., active desmoking).

When either six or all of the targets were visible, the test was terminated and the hangar bay was cleared of smoke. When running tests back to back, the test area was not fully cleared between tests to minimize the turnaround time. Because the performance of each ventilation configuration was based on the initiation of the door configuration, residual smoke in the hangar bay had no effect on the test results.

VISIBILITY RECOVERY CALCULATION PROCEDURE

The measure of effectiveness was the time required for visibility to be recovered. Initiation of ventilation occurred at time 0:00. The effectiveness of the particular wind or ventilation condition was taken as the time (in minutes) to regain visibility of 75% of the targets (e.g., six out of eight). This procedure normalized the varying visibility recovery times for each target and each position to permit comparison of all results. For example, if ventilation was initiated at 30 minutes, and target visibility was restored at 38 minutes, then the ventilation effectiveness was 8 minutes for that particular target location.

TEST RESULTS

A total of seven tests were conducted onboard the USS *Bonhomme Richard* (LHD-6) during the period of 1 through 3 May 2001. The tests evaluated the effect of opening various doors (elevator, flight deck, and well deck) under a headwind or a crosswind. Table 2 provides the test matrix for the tests conducted with the general objective and results of each test. A time line for each test, including visibility observer results and door sequencing, can be found in the appendix.

Wind speed/direction measurements are approximate. Generally, one set of measurements was provided by the bridge either at the start of the test or when ventilation began. The wind directions provided are with respect to the bow. A 90-degree wind would correspond to a "true starboard crosswind" and a 270-degree wind would correspond to a "true port crosswind."

The intent of the tests was to evaluate the effect of a 20- to 30-knot crosswind or headwind in combination with different door configurations. However, the ambient weather conditions did not allow for this type of evaluation. With the exception of Tests 1 and 2, the wind speeds were substantially lower than 20 knots. Also, the wind directions associated with the "crosswind" tests were not true crosswinds (e.g., 90 or 270 degrees). Rather, the wind was offset from the true crosswind. While these conditions were not ideal, the test results still provided some meaningful insight into effective ventilation doctrines.

TABLE 2. Hangar Bay Ventilation Test Matrix and General Results.

Test no.	Test objective	Wind speed/direction (as reported by the bridge)	General results
1	Evaluate effect of crosswind	27-knot port crosswind (190 deg)	Combination of crosswind and two elevator doors resulted in quick removal of smoke. Larger ventilation opening was windward rather than leeward.
2	Evaluate effect of crosswind	17-knot starboard crosswind (165 deg)	Combination of crosswind and two elevator doors resulted in quick removal of smoke. Larger ventilation opening was leeward. Recovery times were shorter than those measured in Test 1 (where larger ventilation opening was windward).
3	Evaluate effect of positive pressure from well deck fans (with well deck ramp door open) and headwind	11- knot headwind	Use of well deck ventilation resulted in quick removal of smoke. Ventilation was cycled first to low speed then to high speed. Low speed is recommended.
4	Evaluate effect of headwind with flight deck ramp door open	11-knot headwind	Headwind and flight deck ramp door had little effect on smoke in hangar bay. This configuration will lead to difficulties in ventilating smoke during a fire event.
5	Evaluate effect of headwind	10-knot headwind (355 deg)	Headwind had little effect on smoke in hangar bay. This configuration will lead to difficulties in ventilating smoke during a fire event.
6	Evaluate effect of crosswind	8-knot crosswind (340 deg)	Configuration of hangar bay did not assist in ventilating smoke quickly. The slow response was attributed to the low wind speed because faster times were measured in Tests 1 and 2 (crosswind tests).
7	Evaluate effect of crosswind with flight deck ramp door open	5-knot crosswind (330 deg)	Configuration of hangar bay did not assist in ventilating smoke quickly. The slow response was attributed to the low wind speed because faster times were measured in Tests 1 and 2 (crosswind tests).

TEST 1 (CROSSWIND TEST)

Test 1 was conducted on 1 May 2001 using a port crosswind (20 to 30 knot at 190 degrees), which was established before opening any doors. The door sequencing began at 39 minutes, after the hangar bay was sufficiently filled with smoke. The door configurations are summarized in Table 3. In contrast to the doctrine, the first ventilation configuration consisted of opening the windward door 1 m (3 ft) rather than the leeward door.

Table 4 summarizes the ventilation effectiveness calculations for the door configurations tested. The results presented in this table show that it took approximately 10 minutes for 75% of the targets to become visible. At this point, both elevator doors were open 3 ft. By the time the port elevator door was opened halfway, visibility of only one target was obscured.

TABLE 3. Test 1 Ventilation Effectiveness Summary.

Time ventilation configuration established, min.	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Port elevator door open 3 ft	n/a	0
5	Port and starboard elevator doors open 3 ft	1-7	88
10	Port elevator door half open, starboard elevator door open 3 ft	1-8	100

Note: Port elevator door was windward; starboard elevator door was leeward.

TABLE 4. Test 1 Ventilation Effectiveness by Target Number.

Target no.	Ventilation effectiveness, min.	Ventilation configuration at visibility recovery
1	6	Both elevator doors open 3 ft
2	10	Both elevator doors open 3 ft
3	6	Both elevator doors open 3 ft
4	7	Both elevator doors open 3 ft
5	9	Both elevator doors open 3 ft
6	10	Both elevator doors open 3 ft
7	8	Both elevator doors open 3 ft
8	11	Port elevator door half open; starboard elevator door open 3 ft

TEST 2 (CROSSWIND TEST)

Test 2 was conducted on 1 May 2001 with a 165-degree starboard crosswind achieved before opening any doors. The door sequencing began at 26 minutes when the hangar bay was sufficiently filled with smoke. The door configurations are summarized in Table 5. During this test and the remaining crosswind tests, the larger ventilation opening was leeward.

The ventilation effectiveness times are summarized in Table 6. These results show that it took approximately 7 minutes to regain visibility of 75% of the targets. With the exception of one target, visibility was recovered when both elevator doors were open 3 ft. The remaining target became visible once the port elevator door was opened halfway. The current baseline ventilation doctrine for amphibious aviation-type ships (open leeward elevator door approximately 1 m (3 ft)) was ineffective; no observers regained visibility of their targets with this setting.

TABLE 5. Test 2 Ventilation Effectiveness Summary.

Time ventilation configuration established, min.	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Port elevator door open 3 ft	n/a	0
5	Port and starboard elevator doors open 3 ft	1, 3-8	88
10	Port elevator door half open, starboard elevator door open 3 ft	1-8	100

Note: Port elevator door was leeward; starboard elevator door was windward.

TABLE 6. Test 2 Ventilation Effectiveness by Target Number.

Target no.	Ventilation effectiveness, min.	Ventilation configuration at visibility recovery
1	6	Both elevator doors open 3 ft
2	13	Port elevator door half open, starboard elevator door open 3 ft
3	7	Both elevator doors open 3 ft
4	7	Both elevator doors open 3 ft
5	6	Both elevator doors open 3 ft
6	6	Both elevator doors open 3 ft
7	6	Both elevator doors open 3 ft
8	6	Both elevator doors open 3 ft

TEST 3 (HEADWIND TEST WITH WELL DECK SUPPLY FANS)

Test 3 was conducted on 2 May 2001 using the well deck supply fans to create a positive pressure in the hangar bay. The fans are located along the walls of the well deck, to provide ventilation during landing craft launch and recovery. With the well deck door closed, the fans provide positive-pressure ventilation to the well deck and the vehicle stowage decks. With the hangar deck/well deck door open, positive-pressure air flows into the hangar deck. When the fans were turned on, they were cycled from low to high speed. The ship also had an 11-knot headwind when ventilation commenced. The door sequencing began at 27 minutes when the hangar bay was sufficiently filled with smoke. Table 7 provides a summary of the door/ventilation configurations that were used. The starboard elevator door was opened as opposed to the port elevator door in order to provide an air sweep through most of the hangar bay. If the port elevator door had been opened, it may have short-circuited the flow of air.

Table 8 lists the ventilation effectiveness for each target. The results show that 75% of the targets were visible within 7 minutes. Visibility of all of the targets returned when the starboard elevator door was open 3 ft and the well deck supply fans were on (with the well deck ramp door open). While the precise time that the fans reached high speed versus low speed was not recorded, it was apparent to the test participants. It was agreed that the draft created when the fans were on high speed could hamper fire-fighting operations. The air sweep provided when the fans were on low speed was deemed sufficient.

TABLE 7. Test 3 Ventilation Effectiveness Summary.

Time ventilation configuration established, min.	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Starboard elevator door open 3 ft	n/a	0
5	Starboard elevator door open 3 ft, well deck ramp door open fully, well deck supply fans on	1-8	100

TABLE 8. Test 3 Ventilation Effectiveness by Target Number.

Target no.	Ventilation effectiveness, min.	Ventilation configuration at visibility recovery
1	7	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)
2	8	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)
3	7	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)
4	7	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)
5	7	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)
6	8	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)
7	6	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)
8	6	Starboard elevator door open 3 ft, well deck supply fans on (well deck door open)

TEST 4 (HEADWIND TEST)

Test 4 was conducted on 2 May 2001 with an 11-knot headwind when ventilation commenced. The hangar bay was sufficiently filled with smoke at approximately 24 minutes and the ventilation sequencing commenced. The door sequencing operations are summarized in Table 9.

Table 10 summarizes the ventilation effectiveness for each target. These results show that it took approximately 20 minutes to regain visibility of 75% of the targets. Target visibility was restored for seven of the eight targets when both elevator doors were open halfway. Visibility of Target 2 was not restored before termination of the test. Observations of the smoke-movement patterns were that the headwind created a "puffing" condition at both of the elevator doors. The lack of a developed inflow or outflow condition at each door resulted in a longer recovery time and the need for both elevator doors to be opened halfway.

TABLE 9. Test 4 Ventilation Effectiveness Summary.

Time ventilation configuration established, min.	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Starboard elevator door open 3 ft	n/a	0
5	Port and starboard elevator doors open 3 ft	n/a	0
10	Starboard elevator door halfway, port elevator door open 3 ft	n/a	0
15	Port and starboard elevator doors open halfway	1, 3-8	88

TABLE 10. Test 4 Ventilation Effectiveness by Target Number.

Target no.	Ventilation effectiveness, min.	Ventilation configuration at visibility recovery
1	20	Both elevator doors half open
2	Did not regain visibility	n/a
3	17	Both elevator doors half open
4	18	Both elevator doors half open
5	17	Both elevator doors half open
6	19	Both elevator doors half open
7	18	Both elevator doors half open
8	20	Both elevator doors half open

TEST 5 (HEADWIND TEST)

Test 5 was conducted on 3 May 2001 with a 10-knot headwind (355 degrees). The hangar bay was sufficiently filled with smoke at approximately 15 minutes and the ventilation sequencing commenced. A shorter time period was required to fill the hangar bay because it was not completely cleared out after Test 4. A summary of the door configurations that were used is provided in Table 11. This test included the use of the flight deck ramp door. In previous tests, it was noted that the smoke did not fill the flight deck ramp area. During this test, smoke moved toward the flight deck ramp door once it was opened. However, a swirling pattern was present at the door; no clear inflow or outflow pattern was established.

The ventilation effectiveness times are summarized in Table 12. These results show that it took approximately 4 minutes to regain visibility of 75% of the targets. The ventilation effectiveness times are shorter for this test than for previous tests because the first door configuration that was used was different. Because none of the targets was visible before the opening of both elevator doors halfway during Test 4, this door setting was used as the initial setting for this test. Therefore, the ventilation effectiveness times cannot be compared directly with those for other tests. Further discussion on this comparison is provided in the Conclusions section.

TABLE 11. Test 5 Ventilation Effectiveness Summary.

Time ventilation configuration established, min.	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Port and starboard elevator doors open halfway, flight deck ramp door open fully	1-5, 7,8	88
5	Starboard elevator door open halfway, flight deck ramp door open fully (port elevator door closed)	1-8	100

TABLE 12. Test 5 Ventilation Effectiveness by Target Number.

Target no.	Ventilation effectiveness, min.	Ventilation configuration at visibility recovery
1	1	Both elevator doors half open, flight deck door open
2	3	Both elevator doors half open, flight deck door open
3	3	Both elevator doors half open, flight deck door open
4	3	Both elevator doors half open, flight deck door open
5	7	Both elevator doors half open, flight deck door open
6	9	Starboard elevator door half open, flight deck door open
7	2	Both elevator doors half open, flight deck door open
8	4	Both elevator doors half open, flight deck door open

TEST 6 (CROSSWIND TEST)

Test 6 was conducted on 3 May 2001 using an 8-knot port crosswind (340 degrees) when ventilation commenced. The hangar bay was sufficiently filled with smoke at approximately 35 minutes and the ventilation sequencing began. The door positions that were used during this test are summarized in Table 13.

The ventilation effectiveness times are summarized in Table 14. From this table, 75% of the targets were visible at 21 minutes. At this time, the starboard elevator door was open fully and the port elevator door was open halfway. Visibility of 5 of the targets was restored when both elevator doors were open halfway (before opening the starboard elevator door fully).

Although the recovery times are longer than those measured in crosswind Tests 1 and 2, the configuration was effective. Observers confirmed that the air was flowing in through the port elevator door and out through the starboard elevator door. The difference in smoke removal times was attributed to the lower ambient wind speed that was present during this test.

TABLE 13. Test 6 Ventilation Effectiveness Summary.

Time ventilation configuration established, min.	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Starboard elevator door open 3 ft	n/a	0
5	Port and starboard elevator doors open 3 ft	n/a	0
10	Starboard elevator door open halfway, port elevator door open 3 ft	n/a	0
15	Starboard and port elevator doors open halfway	1, 3, 4, 7, 8	63
20	Starboard elevator door open fully, port elevator door open halfway	1-8	100

Note: Starboard elevator door was leeward; port elevator door was windward.

TABLE 14. Test 6 Ventilation Effectiveness by Target Number.

Target no.	Ventilation effectiveness, min.	Ventilation configuration at visibility recovery
1	17	Both elevator doors half open
2	22	Starboard elevator door full open, port elevator door half open
3	16	Both elevator doors half open
4	17	Both elevator doors half open
5	21	Starboard elevator door full open, port elevator door half open
6	22	Starboard elevator door full open, port elevator door half open
7	17	Both elevator doors half open
8	17	Both elevator doors half open

TEST 7 (CROSSWIND TEST)

Test 7 was conducted on 3 May 2001 using a 5-knot crosswind (330 degrees) when ventilation commenced. The door sequencing began at 27 minutes when the hangar bay was sufficiently filled with smoke. The door positions are summarized in Table 15. As with Test 5, the initial door position was different from that in other tests. Two door positions were not evaluated explicitly because earlier tests showed that these configurations were not very effective for removing smoke.

Table 16 summarizes the ventilation effectiveness calculations. This table shows that 75% of the targets were visible at 11 minutes. At this time, the starboard elevator door was open fully, the port elevator door was open halfway, and the flight deck ramp door was open fully. Visibility of five of the targets was restored during the previous door configuration, with both elevator doors open halfway and the flight deck ramp door open fully. Visual observations of the air-flow pattern through the flight deck door were that it did not contribute to the smoke-removal process.

Because the initial door configuration was different from that used in previous tests, the recovery times cannot be compared directly with those from other tests. Further discussion about this comparison is provided in the Conclusions section.

TABLE 15. Test 7 Ventilation Effectiveness Summary.

Time ventilation configuration established, min.	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Starboard elevator door open halfway, port elevator door open 3 ft, flight deck ramp door open fully	n/a	0
5	Port and starboard elevator doors open halfway, flight deck ramp door open fully	1, 3, 4, 7, 8	63
10	Starboard elevator door open fully, port elevator door open halfway, flight deck ramp door open fully	1-8	100

Note: Starboard elevator door was leeward; port elevator door was windward.

TABLE 16. Test 7 Ventilation Effectiveness by Target Number.

Target no.	Ventilation effectiveness, min.	Ventilation configuration at visibility recovery
1	9	Both elevator doors half open, flight deck door open
2	11	Port elevator door half open, starboard elevator door fully open, flight deck door open
3	6	Both elevator doors half open, flight deck door open
4	7	Both elevator doors half open, flight deck door open
5	11	Port elevator door half open, starboard elevator door fully open, flight deck door open
6	17	Port elevator door half open, starboard elevator door fully open, flight deck door open
7	6	Both elevator doors half open, flight deck door open
8	8	Both elevator doors half open, flight deck door open

COLD-SMOKE LIMITATIONS

The tests conducted onboard the USS *Bonhomme Richard*, and onboard the USS *Eisenhower* (Reference 7), used cold smoke rather than hot smoke, which would be produced during an actual fire event. The use of cold smoke introduced some limitations to the tests because it lacked the buoyancy characteristics of real fire smoke. The density differences

between hot and cold smoke are critical for evaluating smoke accumulation and movement within a fire space. During a fire event, ambient air is drawn into the fire compartment at the deck level, is passed through the fire where it is heated, and then is pumped up into the overhead. As the smoke layer builds, the hot smoke eventually spills or vents out the top of the fire compartment and spreads to adjacent compartments or outside. In the presence of a vent opening, strong air currents will develop naturally drawing fresh cool air into the fire and pumping the hot smoke into the overhead and out of the compartment. Flowing through the fire creates the density differences required for the smoke to rise to the overhead and accumulate before venting out of the compartment. If no vents are present (i.e., all doors shut), the smoke layer will build and descend down to the deck, reducing visibility to zero.

Because cold smoke lacks the buoyant forces present in a real fire, it can be removed only by air currents developed by natural or mechanical ventilation. Therefore, in the testing conducted onboard the USS *Bonhomme Richard*, the cold smoke would have eventually settled in the hangar bay in the absence of ventilation. During an actual fire event, however, the buoyant forces generated by the fire are powerful enough to vent themselves, even under still-air conditions. Applying this principle to the test results, the actual ventilation times may be reduced. In other words, hot smoke is more efficient in venting itself, especially when no mechanical ventilation is present as is the case in an amphibious assault ship hangar bay. This smoke venting and spread can also work against firefighting operations because the smoke will spread on its own, infiltrating unaffected spaces, degrading visibility and leading to increased disorientation.

In Australia and New Zealand, all new buildings are required to demonstrate satisfactory performance of the installed smoke control systems when evaluated during a hot smoke test (Reference 8). To perform the hot-smoke test, metal fire pans are filled with a predetermined amount of denatured methylated spirits to produce the desired fire size. Methylated spirits are used in lieu of other flammable liquids because of the cost effectiveness, clean combustion byproducts, and low radiation output and because no visible flame occurs. The metal fire pans are placed within larger water-filled metal pans. These water-filled pans prevent heat transfer from the fire pans to the supporting structure. A smoke generator is positioned near the edge of the fire pans to inject smoke into the hot buoyant plume for dispersal throughout the building. This test arrangement allows for a safe, controlled, and clean method to evaluate the performance of an installed smoke control system under simulated fire conditions.

CONCLUSIONS

The NATOPS firefighting manual provides guidance for ventilating smoke generated during a fire event in a hangar bay of an amphibious assault ship (Reference 1, Chapter 8). The guidance, in the form of a note, allows for using cross ventilation to facilitate smoke removal. The intent of this guidance is to reduce the heat and smoke threat to the firefighting personnel.

Testing was conducted onboard the USS *Bonhomme Richard* (LHD-6) to evaluate the effectiveness of opening a hangar bay door approximately 1-m (3-ft) under both crosswind and headwind conditions. Results of the testing indicated that irrespective of the ambient wind

conditions (headwind or crosswind), opening the windward or leeward elevator door approximately 1 m (3 ft) had minimal effect on reducing the smoke level within the hangar bay. Based on these test results, further testing was conducted to determine the most effective door configuration for removing smoke from a hangar bay under various ambient wind conditions (crosswind and headwind). The use of mechanical ventilation to pressurize the hangar bay was also examined. This condition was created by opening the well deck ramp door and turning the well deck supply fans on.

To compare the smoke removal times for each ventilation configuration, the times were adjusted for Tests 5 and 7. When ventilation began during Test 5, three of the door-sequence operations that were used for Tests 1 through 4 were not used explicitly (i.e., open leeward door 1 m (3 ft), open windward door 1 m (3 ft), and open leeward door halfway). Therefore, 15 minutes were added to the smoke-removal time so that the results from Test 5 could be compared to the other tests. Similarly, two-door sequence operations were not evaluated explicitly during Test 7 (i.e., open leeward door 1 m (3 ft) and open windward door 1 m (3 ft)). As a result, 10 minutes were added to the smoke removal time for this test. Results for each of the tests are summarized in Table 17. The most effective door configuration corresponds to the ventilation setting that existed when 75% of the targets were visible.

TABLE 17. Comparison of Time to Restore Visibility (75% of Targets).

Test no.	Ventilation conditions	Most effective door configuration	Time to restore visibility, min.
1	27-knot crosswind (larger vent. opening windward)	Both el doors open 1 m (3 ft)	10
2	17-knot crosswind	Both el doors open 1 m (3 ft)	7
3	11-knot headwind with positive pressure from well deck supply fans	Starboard el door open 1 m (3 ft), well deck supply fans on (well deck ramp door open)	7
4	11-knot headwind (using flight deck ramp door)	Both el doors open halfway	20
5	10-knot headwind	Both el doors open halfway, flight deck ramp door open	19[a]
6	8-knot crosswind	Starboard el door open fully, port el door open halfway	21
7	5-knot crosswind (using flight deck ramp door)	Starboard el door open fully, port el door open halfway, flight deck ramp door open	21[a]

[a]Times corrected for differences in ventilation sequencing.

Based on the test results, a crosswind provided improved ventilation effectiveness compared to a headwind. During Test 2, when there was an ambient crosswind of 17-knots, smoke was removed in 7 minutes. Although the wind speed was higher during Test 1, the smoke removal time was longer. This result was attributed to having the larger ventilation opening on the windward side. Whenever possible, the larger ventilation opening should be on the leeward side. The smoke removal time for the other crosswind test that only used the elevator doors, Test 6, was longer than for Tests 1 and 2. The removal time for Test 6 was 21 minutes as compared to 10 and 7 minutes for Tests 1 and 2, respectively. The difference in removal times is likely the result of the low wind speed that was present during Test 6.

The smoke removal times measured for tests that incorporated a headwind were longer than those measured for crosswind Tests 1 and 2. Visual observations confirmed that this configuration was not effective for removing smoke.

The use of the flight deck ramp door did not enhance the smoke removal from the hangar bay with headwind or crosswind conditions. Because of the location of the door, it was anticipated that it may assist with providing a sweep through the hangar bay, particularly under headwind conditions. However, visual observations confirmed that the opening was not established as an inflow or outflow path.

Based on the results from the test conducted using the well deck supply fans (Test 3), this technique may be at least as effective as using an ambient crosswind. This technique would be effective regardless of the ambient wind conditions. As experienced during these tests, the ambient wind conditions are not always sufficient for creating substantial crosswinds. Therefore, the use of the well deck supply fans could provide a valuable option for smoke removal techniques.

The conclusions presented in Table 17 are based on a limited number of tests using cold smoke. Cold smoke does not have any natural buoyancy and, therefore, relies solely on air currents to move the smoke. As a result, the effect of fire-induced buoyancy was not addressed in this testing. The hot smoke will flow out of an opening and, in certain cases, overcome the ambient conditions. It is not considered necessary to conduct hot-smoke tests in a hangar bay to confirm these results because the ventilation effectiveness would likely improve as a result of the added buoyancy induced during a simulated-fire evaluation. Additionally, on-scene personnel would adjust the door configuration to suit the specific fire to optimize the outflow of hot smoke and gasses with the ambient wind conditions.

These results are consistent with those obtained during tests on the USS *Eisenhower,* a *Nimitz*-class aircraft carrier. Similar to the LHD-6 tests, the results showed that opening an elevator door 1 m (3 ft) had minimal effect on smoke removal from the hangar bay, regardless of the ambient wind conditions. Smoke removal was the quickest when doors were opened on the port and starboard sides of the hangar bay. For situations where elevator doors were on each side of the hangar bay, the results suggested that the most effective door configuration was to open the leeward door halfway and the windward door 1 m (3 ft) (assuming that the ship has turned to create a crosswind).

RECOMMENDED CHANGES TO NATOPS MANUAL

Incorporating the test results and conclusions previously discussed, recommended changes to Chapter 8 of the NATOPS firefighting manual have been developed (Reference 1). These changes are specific to LHD *Wasp*-class ships. To balance accurate guidance without being overly restrictive to the personnel implementing the doctrine, it is recommended that Section 8.7.6 (Reference 1) read as follows:

8.7.6 Hangar Deck. The following additional procedures for aircraft fires on the hangar deck of LHD ships shall be followed:

1. Return elevators to the flight deck level.
2. Close fire doors immediately.

For natural ventilation conditions:

3. Open elevator door closest to the fire halfway. Request the ship to execute a turn in order to position this door to leeward.
4. Open windward elevator door approximately 3 ft to facilitate venting of smoke.

For mechanical ventilation:

3. Open the starboard elevator door 3 ft.
4. Open the well deck ramp door fully. Turn well deck ventilation onto low speed to pressurize hangar bay and vent smoke.
   Note: This procedure should be used only for situations in which there is no threat of the fire spreading into the well deck or of fuel flowing down the ramp.

5. Leave all hangar deck lights on.
6. Close all weapons elevator doors and hatches.
7. All firefighting team members shall don OBA/positive-pressure breathing apparatus as soon as possible.
8. Post cooling teams on opposite sides of doors.
9. Activate appropriate zones of the hangar bay AFFF sprinkler system for any multi-aircraft fire or when a spill fire is judged to be beyond the capability of the initial hose team.

Although some configuration differences exist between the hangar bays of the LHD amphibious-aviation type ships and an aircraft carrier, the test results and conclusions described in this report are similar. The proposed changes follow the same rationale recommended for the aircraft carriers in that a crosswind should be established. The largest door opening should be on the leeward side of the ship.

However, because configuration differences exist between the hangar bays of LHA and LHD amphibious assault ships, these test results and conclusions may not be directly applicable. Therefore, proposed changes to Chapter 8 of the NATOPS Manual for LHA ships should be developed based on similar testing and analysis. Development of procedures for LPH ships is not necessary because these ships have been decommissioned.

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Appendix
TEST EVENT FOR VENTILATION TIME LINES
(Note: times rounded to nearest number)

TABLE A-1. Test 1, Wind Condition Evaluated: Crosswind
Actual Ambient Wind Conditions: 27-Knot Port (190 Degrees) Crosswind

Time, min.	Event	Time visibility lost by target no.	Time visibility regained by target no.
0	Smoke generators on	---	---
22	---	2	---
27	---	6	---
31	---	1	---
33	---	5	---
35	---	8	---
40	---	4	---
42	---	3,7	---
43	Port el door open 3 ft	---	---
49	Starboard el door open 3 ft	---	---
50	---	---	1,3
52	---	---	4,5,7
53	---	---	2
54	Port el door open halfway	---	6,8

TABLE A-2. Test 2, Wind Condition Evaluated: Crosswind
Actual Ambient Wind Conditions: 17-Knot Starboard (165 Degrees) Crosswind

Time, min.	Event	Time visibility lost by target no.	Time visibility regained by target no.
0	Smoke generators on	---	---
14	---	2	---
15	---	1,8	---
17	---	4,6	---
19	---	7	---
20	---	3	---
22	---	5	---
26	Port el door open 3 ft	---	---
32	Starboard el door open 3 ft	---	1,5,6
33	---	---	3,7,8
34	---	---	4
37	Port el door open halfway	---	---
39	---	---	2

Note: Test began with residual smoke from previous test.

TABLE A-3. Test 3, Wind Condition Evaluated: Headwind with positive pressure from well deck ventilation
Actual Ambient Wind Conditions: 11-Knot Headwind.

Time, min.	Event	Time visibility lost by target no.	Time visibility regained by target no.
0	Smoke generators on	---	---
6	---	2	---
7	---	1	---
19	---	4	---
21	---	8	---
23	---	3	---
24	---	6	---
25	---	7	---
27	Starboard el door open 3 ft	5	---
32	Well deck ramp door open	---	---
33	Well deck ventilation on	---	7,8
34	---	---	1,3,4
35	---	---	5,6
36	---	---	2

TABLE A-4. Test 4, Wind Condition Evaluated: Headwind
Actual Ambient Wind Conditions: 11-Knot Headwind.

Time, min.	Event	Time visibility lost by target no.	Time visibility regained by target no.
0	Smoke generators on	---	---
12	---	2	---
14	---	6	---
17	---	5,8	---
19	---	7	---
22	---	4	---
23	---	1	---
24	Starboard el door open 3 ft	3	---
30	Port el door open 3 ft	---	---
35	Starboard el door open halfway	---	---
39	Port el door open halfway	---	---
41	---	---	3,5
42	---	---	7
43	---	---	4
44	---	---	1,6,8

TABLE A-5. Test 5, Wind Condition Evaluated: Headwind
Actual Ambient Wind Conditions: 10-Knot Headwind (355 Degrees).

Time, min.	Event	Time visibility lost by target no.	Time visibility regained by target no.
0	Smoke generators on	---	---
1	---	4	---
2	---	6	---
3	---	3,5	---
5	---	8	---
8	---	7	---
13	---	1	---
15	Both el doors open halfway, flight deck ramp door open fully	---	---
16	---	---	1,7
17	---	---	3
18	---	---	2,4,8
21	---	---	5
22	Port elevator door closed	---	---
23	---	---	6

Note: Test began with residual smoke from previous test.

TABLE A-6. Test 6, Wind Condition Evaluated: Crosswind
Actual Ambient Wind Conditions: 8-Knot Port Crosswind (340 Degrees).

Time, min.	Event	Time visibility lost by target no.	Time visibility regained by target no.
0	Smoke generators on	---	---
18	---	6	---
20	---	5	---
22	---	4,8	---
25	---	7	---
26	---	2,3	---
33	---	1	---
35	Starboard el door open 3 ft	---	---
39	Port el door open 3 ft	---	---
44	Starboard el door open halfway	---	---
50	Port el door open halfway	---	---
51	---	---	3,7
52	---	---	1,4,8
55	Starboard el door open fully	---	5
56	---	---	6
57	---	---	2

TABLE A-7. Test 7, Wind Condition Evaluated: Crosswind
Actual Ambient Wind Conditions: 5-Knot Port Crosswind (330 Degrees).

Time, min.	Event	Time visibility lost by target no.	Time visibility regained by target no.
0	Smoke generators on	---	---
8	---	6	---
13	---	4	---
14	---	5	---
15	---	2,8	---
18	---	7	---
20	---	3	---
26	---	1	---
27	Port el door open 3 ft, starboard el door open halfway, flight deck ramp door open fully	---	---
32	Starboard el door open halfway	---	---
33	---	---	3
34	---	---	7
35	---	---	4,8
36	---	---	1
38	Starboard el door open fully	---	5
39	---	---	2
45	---	---	6